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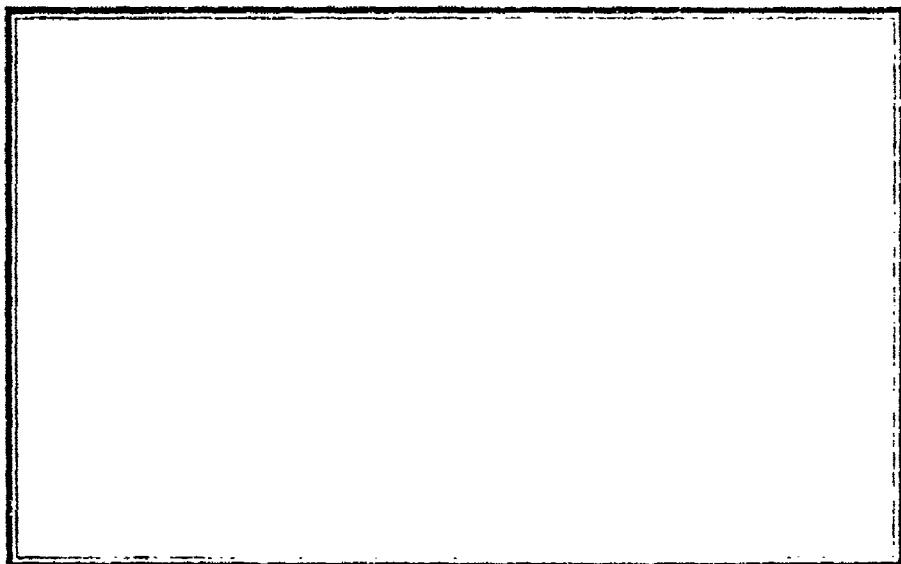
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Edwards Street Laboratory  
Yale University  
New Haven, Connecticut

Study of Air-Laid  
Nine Water Entry Disturbances  
- 1951 - 1953 at  
Edwards Street Laboratory

Andrew Patterson, Jr.

Technical Report No. 19  
(ESL:570:Serial 0123)  
17 November 1953

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Work in passive underwater sound ranging carried out by a group at the Edwards Street Laboratory originated in 1951 shortly after this project was instituted. It appeared that it might be profitable to investigate passive acoustic ranging as a means of locating air laid mine water entry points. Previous interest in the nature of missile water entry disturbances had resulted from a study made in 1948 by A. Patterson at the Underwater Sound Laboratory on scanning sonar capabilities in anti-submarine warfare. A favored method of attack against a submarine is to use an acoustically-guided air-launched torpedo, and the question was raised just how typical and distinguishable the sound of its water entry might be. There was no direct information available on this point in 1948.

The present report brings up to date a statement of the work which has been done and the results which have been obtained by the Edwards Street Laboratory on mine water entry disturbances. A more elaborate description of the scientific details is in preparation for submission to the Journal of Underwater Acoustics. References to previous Edwards Street Laboratory reports are included herewith.

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During the summer of 1951 Edwards Street Laboratory personnel made some recordings off a pier at the Naval Torpedo Station at Gould Island of experimental torpedo and ordnance drops near by. This preliminary work indicated that the sounds were not especially loud or distinctive, and that more careful studies of the sounds would be required.

On investigation we found already in existence a Navy Ordnance system of shore controlled ground mines as part of which a group of audio-range hydrophones and accessory equipment, the so called Mark 6 Acoustic System, was provided. It seemed probable that the hydrophones of this system could be utilized as part of a passive ranging unit with suitable modifications or additions, if it were found that the mine water entry signatures were detectable at long enough distances.

Overtures were made to the Navy to install such a system, or parts thereof, at New London harbor. By November 1951 a group of four hydrophones and the usual shore equipment had been installed between Fishers Island and New London Ledge Light, with the shore gear at the NECP on Fishers Island. Meanwhile, plans were taking form for Operation MUD, so work on this Mk 6 system was laid aside temporarily while equipment was readied for MUD. Far from being time wasted, however, the

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experience gained with and measurements made on the Mk 6 system were invaluable, since a full installation of the gear was found in operation at Yorktown.<sup>1</sup> During this period it was also found that Naval Mine Depot personnel at Yorktown had used the Mk 6 Acoustic System to listen to mine water entries. The results appeared to be encouraging. Due to a lack of suitable recording equipment, however, no attempt had been made by the Yorktown group to study the water entry sounds in detail. Special efforts were thus made by ESL to obtain permanent records of the sounds produced by mine water entry.

At Yorktown we were able to obtain the first acoustic recordings of full scale mine water entry signatures. Three small angle-iron tripods were placed in the river, each with a seismometer (a dynamic microphone-moving coil device) and a wide frequency range barium titanate hydrophone, connected to shore by such cable as we were able to obtain in the space of a few months. A moving pen-permanent record oscillograph and magnetic tape recorders were the data recording units. Between cable leaks, cable changes, and other field operational difficulties, we managed to obtain a number of excellent

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(1) ESL TR 7, "Experimental Study of Mk 6 Acoustic System",  
28 April 52.

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recordings of Mk 36 mines, but all the Mk 39 mines had to be recorded over the Mk 6 Acoustic System, the wide band acoustic performance of which leaves much to be desired.<sup>2</sup>

Meanwhile, as a joint effort between the Underwater Sound Laboratory, ESL, and the Naval Ordnance Test Station at Pasadena, the water entry behavior of a group of Mk 13 torpedoes, special missiles, and Mk 36 mines were studied under excellent laboratory conditions at the Morris Dam Station of NOTS. These measurements complemented in every way our work at Newport and Yorktown, but provided numerical data on intensities not obtained at Yorktown.<sup>3</sup>

In the spring of 1952 after Operation MUD was over, the Mk 6 Acoustic System installed at Fishers Island was used to test the practicability of sound ranging with such equipment with blasting caps as idealized sound sources. (Blasting caps are much louder than a typical mine water entry, for the very short period during which they produce a signature). We were able to show that location precisions of 5 feet were theoretically possible, but the accuracy of location was highly conditioned by the ability to locate the

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(2) ESL TR 6, "Preliminary Report on Acoustic Studies for Operation MUD" of 28 March 52, and TR 8, "Final Report on Acoustic Studies for Operation MUD" of 10 Sept. 52.

(3) NOTS TM 660, "Water Entry Noise Study of Air Launched Missiles", of 22 July 52.

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hydrophones geographically at known points, and by errors accumulating in any plotting procedures. It was nevertheless clear that passive ranging could be accomplished with already existing acoustic gear. Plans were considered for an automatic recording-computing system to analyze the splash noise data. We are still working on this point.<sup>4</sup>

During summer 1952 we attempted to make an acoustic range installation in the West Passage at Jamestown, Rhode Island. This was doomed to failure by the same thing which had already caused so much trouble---cable. We used what we had or could get, found by bitter experience how to lay it from an L-Boat, and finally, on getting it in operation, found that a 30-mile distant Air Force Alexanderson Alternator putting out 50 KW of 25.8 KC power modulated by teletype signals almost produced enough signal to light a light on the open ends of the cable. Some recordings were finally made in September, marred by much snap, crackle, and pop from the teletype modulation.

At this point, we decided to purchase some adequate cable, a sample of which is shown in Figure 1.

This consisted of 7 twisted pairs double shielded, insulated, armored, and covered with a plastic sheath. This was installed, together with three pontoons and much-improved shore equipment, in the West Passage and in the

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(4) ESL TR 9, "Report on Use of Mk 6 Acoustic System for Sound Ranging", 12 August 52.

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small house known as T-21 during the summer of 1953. Three pontcons of standard Navy type were used in 1952, and again in 1953, to mount the underwater units. The Figures which follow show some features of the installation, Figs. 2-6.

A brief recorded sample of the following mine water entry sounds is available on standard magnetic tape for any organization desiring to request a short-term loan thereof.

- a. Mk 39 (free fall)
- b. Mk 39 with airplane noise (free fall)
- c. Mk 25 (parachuted 2000 lb. mine)

We have found that the water entry sounds of missiles so far studied fall into two groups - those like Mk 36 mines, those like Mk 39's. The difference seems to be due to the behavior after water entry. The discussion below is simplified this way - but torpedoes and Mk 25 mines have been found to sound the same, essentially, as Mk 36 mines. (High speed missiles such as antisubmarine bombs give a very simple signature.) Fig. 7 is an oscillogram of a Mk 36 signature. The water entry events which correspond to this oscillogram are shown in Figure 8, in the upper line. (This Figure was prepared from films of model tests made at the Naval Ordnance Laboratory. Selected frames showing the critical features of the underwater trajectory have been sketched for clarity of reproduction.) Reading from left to right, the events are

- a. water contact

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- b. water entry
- c. cavity formation
- d. full length of mine slaps side of cavity
- e. cavity continues to enlarge
- f. cavity continues to enlarge
- g. closure of cavity beginning close to mine
- h. closure complete around mine and progressing toward surface

In the moving picture film of the event, the smoothness, but rapidity, of the cavity closure is striking, as is also the fact that very, very little gas or vapor is left around the mine after closure. The cavity itself simply disappears toward the surface.

The two prominent peaks in Mk 36 and Mk 13 torpedo water entry signatures correspond to water contact and to the missile slap against the cavity. This requires only a short period of time ~ 0.05 second perhaps - which period in part depends upon the missile and its aspect with respect to the water. This series of events was postulated by us during the summer of 1952 and first published in ESL TR 8, ref. 2, dated 10 September 1952. It is gratifying to find these postulations borne out by later careful experimental work referred to below.

We have now an oscillogram of a Mk 39 water entry si...- nature, Fig. 9.

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(Note that the time scale is four times as long as in the Mk 36 example shown in Fig. 7.) The beginning of the Mk 39 oscillogram and the underwater entry event are similar to the Mk 36 example, in that water contact and cavity side slap are both observed as before. The lower line of figure 8 shows critical stages in the Mk 39 entry. As before we observe:

- a. water contact
- b. water entry
- c. cavity formation
- d. full length of mine slaps side of cavity
- e. cavity continues to enlarge

However, a different course is followed from this point on:

- f. cavity closes at surface
- g. mine and cavity both move downward in water
- h. portion of cavity (on left in sketch) where mine originally slapped side of cavity continues downward at considerable speed before rising

The entire event is much more prolonged. Presumably the cavity closure is the source of the delayed second peak observed on the oscillogram. The large entrapped air and vapor mass finally rises to the surface.

Simultaneous photographic and acoustic recordings of model tests similar to those from which these sketches

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were taken have been made by Catholic University personnel using facilities at NOL, for Mk 36's.<sup>5</sup> There are additional sound peaks which appear after and between the two major spikes which must be due to vibration of the mine body, coupled to the water. Similar recordings are now being made at our request on Mk 39 models. Further correlation on the details of the Mk 39 signature which we have proposed above will have to await completion of these measurements.

We have analyzed all our good laboratory quality recordings in the range of frequencies from about 50 cps to 15 Kcps (the useful range of the magnetic tape recorders) in terms of amplitude vs frequency, and have found an apparently most favorable signal/noise ratio near 100-200 cps.<sup>6</sup> This applies only to Mk 36's since it was only for these that good data were available. The frequency response of the Mk 6 Acoustical System was too distorted to permit this type

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(5) Final Report on Contract Nonr 894(00), "Model Experiments on Acoustic Signals from Air Dropped Mines, dated 31 Dec 1952.

(6) ESL TM 15, "Analysis of Mine-drop Signatures for Rise-time, Amplitude, and Frequency Characteristics" of 30 March 1953.

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of analysis of the data on Mk 39 recordings made at Yorktown. See Fig. 10. During the past summer we have made numerous excellent recordings of Mk 39 drops. Analysis of these data in the same manner will proceed through the winter of 1953-1954.

Mine water entry signatures may be received from considerable distances. The S/N ratio is such as to permit reception of Mk 36's from a range of at least 1500 yards under reasonable conditions, or Mk 39's from as much as 6000 yards in some unusual circumstances. At such large ranges, the signatures exhibit a number of well recognized propagation distortions such as: ground wave pre-arrival, wave-guide-like channelling and frequency selectivity, and other odd but explainable peculiarities. These distortions suggest that hydrophones will have to be provided at moderately short ranges - 1000 yards perhaps, if not less - before any degree of precision of location would be possible. This is not an encouraging thought in terms of hydrophone cost and cable complexity. Recently<sup>7</sup> workers at NOL have reported on their experience in passive ranging at the Dahlgren

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(7) Eighth Navy Underwater Sound Symposium, 19-20 Nov 1953, Papers C7 and C8, "Acoustic and Seismic Detection and Location of Mine and Missile Splashes-Parts I and II, by J. C. Munson and H. N. Opland.

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proving range. Our findings complement those reported by Messrs. Opland and Munson in every way, but with a shift of emphasis. If recordings are made from hydrophones or seismometers located at ranges of 1500 yards or more from the water entry point, the signatures received will be markedly distorted to the point that they not only will fail to resemble the actual event but may be of little value for ranging purposes. This statement depends upon the frequencies received and the band width used, quite naturally. All our recent measurements and recordings have been made at as short range as possible in order to permit us to record the full frequency-phase-time content of the signature, unmodified by propagation distortion. Measurements made at large ranges are of no value in revealing the true character of the disturbance, although they might be interpreted in light of normal-mode propagation theory to give the layer depths of the geological formations in the area. One may compare the first portion of the oscillograph record in Figure 11 with the Kk 36 mine signature oscillogram shown in Fig. 7 to get an idea of the distortion observed at a moderate range (1000 yards) compared to very short range (200 feet). The pre-arrival disturbance following the very short portion of background shown at the beginning of the trace is very noticeable. The main

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arrival occurs some 0.3 second later.

Meanwhile, Kelpar, of Alexandria, Virginia, has proposed a device which will act as a ~~beacon~~, to sense and to herald for a useable period and at a considerable range the arrival of a mine-like object. This device, perhaps, ideally, as small, simple and inexpensive as a can of beer, can be sown at random in harbors. The peculiar requirements for success of such an idea are fairly obvious - simplicity and low cost being paramount. Since cable, cable laying, and maintenance cost so much, this may yet turn out to be a cheap approach to the problem of localizing a mine water entry splash. For equipment simplicity, it may be well to employ the lowest frequencies possible. Since we have felt that lack of knowledge of the character of mine water entry signatures was a prime stumbling block, however, we have emphasized the collection and analysis of such data, and will continue to do so.

Further analysis of audio frequency data and a comparison with typical background noise in harbors (by Kelpar) indicates that a successful audio band short range discriminator between mines and other harbor noise may be able to depend upon amplitude and simple frequency differences alone.

Nothing in detail has been said thus far about the low-frequency character of these acoustic signals. In Figure 11

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is shown a tracing taken from a paper tape oscillogram of a mine drop at about 1000 yards distance. Not only is the pre-arrival, and other modification of the signal apparent, but more striking yet is the high level low frequency oscillation which starts about eight seconds after the water entry disturbance has reached the hydrophone. The frequency response of the oscillograph limits the upper frequency range of this recording to 150-200 cps. Although this is a region where there is undoubtedly considerable energy available, it is unhappily still a field about which we know the least. Originally we had hopefully expected that it might be possible to hear the mine hit the bottom - not the surface. Accordingly we stuck seismometers in the mud at operation MUD to pick up the thud on the bottom. Somewhat reassuringly, but not until we had puzzled over the fact, we found that the hydrophone 3 feet above the bottom and the seismometer in the bottom gave exactly the same signals in the same low frequency range. The coupling between the two media is intimate. Both types of receivers gave signals which can be described only as undulations, the appearance of which correlated with and followed the mine water entry event. No satisfactory theoretical explanation or experimental correlation with this observation had been made until the summer of 1953, when we found that simply dropping a mine, already

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in the water, at the surface, tied on a retrieving line, through a 40 foot fall to the bottom gave similar undulations. See Figure 12. The 10 second delay correlates with the lack of water entry velocity, but agrees with the known fact that a mine rapidly attains its terminal water speed in a very short time. The fact that similar oscillations are observed unequivocally establishes that they result from the mine colliding with the bottom. A suitable explanation of this phenomenon is still lacking, but it is unquestionably connected with the mine hitting the harbor bottom. If this large amount of energy is available in this very low frequency range, the Kelpar beer-can device may possibly consist of only a diaphragm, some orifice-coupled liquid-filled chambers, and a simple sensing device. We have never observed disturbances of this type associated with other underwater events, the mine signature undulations are comparatively unique; we shall obviously pursue this question at some length.

Comments are invited.

In the course of making acoustic observations in the West Channel, we have found reverberations and numerous other acoustic transmission phenomena which are explainable in terms of the underwater terrain, including a sudden disappearance of signal when the signal source (e.g., a boat) passes over the shelf, where the water depth suddenly

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increases as one proceeds in a southerly direction down the channel. This effect is most pronounced - so much so that for a time we thought we had equipment difficulties.

Our future plans include, beside the completion of analysis of the recordings obtained during the summer of 1953, the construction of black boxes to see the simplest effective way in which we can discriminate and identify a mine water entry from other harbor noises, in order to operate a frequency-counter type of timing recorder. This is similar to the job Nelpar has to do, and the two efforts complement each other. This can be done synthetically in the laboratory here with data already recorded and ready for use. We will then be in a position to make a realistic system proposal, which can use at least in part equipment which is already available to harbor defense installations for the job of positively locating mine splashes by acoustic means.

We shall obviously spend considerable time on the interpretation of the fascinating low frequency bottom collision undulations, in terms of range variation, absolute signal level, frequency character, influence of missile size and speed, bottom character, and so on.

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It also is desirable to collect additional data on missile water entry whenever possible to provide a statistical basis for establishing the degree and extent to which mine water entry signatures are characteristic, typical, and recognizable.

In order to make this program realistic it will be necessary to make recordings of full scale drops of such Russian mines as are available, preferably using dummy full scale models based on the best intelligence information available.

The writer wishes to acknowledge with appreciation the assistance of his colleagues, Prof. W. W. Watson, Messrs. R. G. Wheeler, R. K. Waring, J. W. Corbett, R. E. Lanou, Jr., S. D. Elliott, Jr., and D. P. Mann, as well as LCDR. N. H. Prade, formerly of the NMD, Yorktown and Dr. Halley Wolfe of NOTS. The personnel of the NMD, Yorktown, the U. S. Navy Underwater Sound Laboratory, New London, the Edwards Street and Beavertail Laboratories who have been of great aid at one time or another are too numerous to mention, but deserve grateful thanks nonetheless.

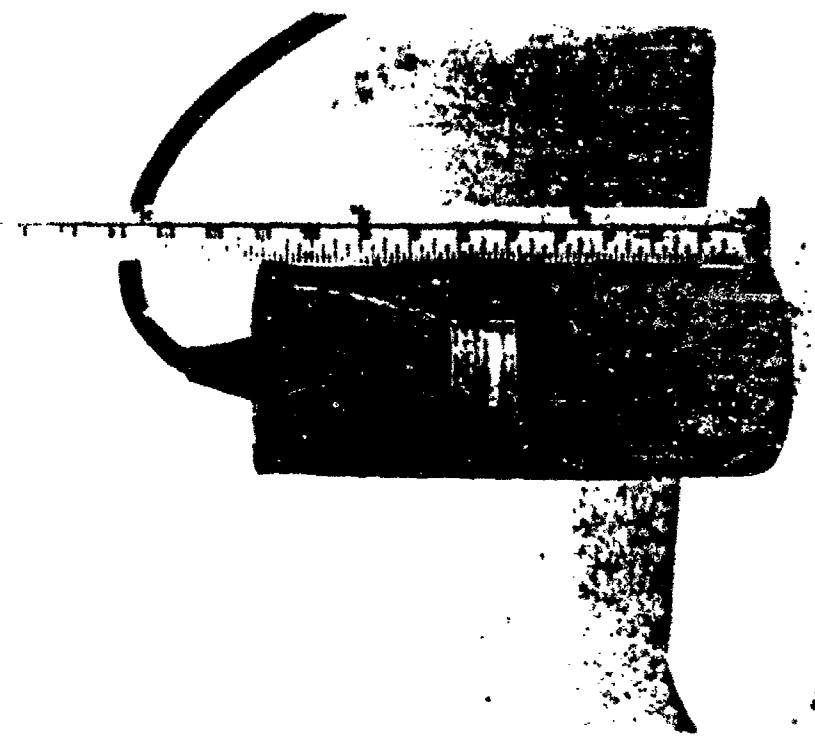


Andrew Patterson, Jr.  
Research Associate

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Fig. 1 -- Sample of 7-pair underwater cable  
(left). Typical rubber-encased  
hydrophone or seismometer (right).  
(Both cable and seismometer  
shown at same enlargement.)

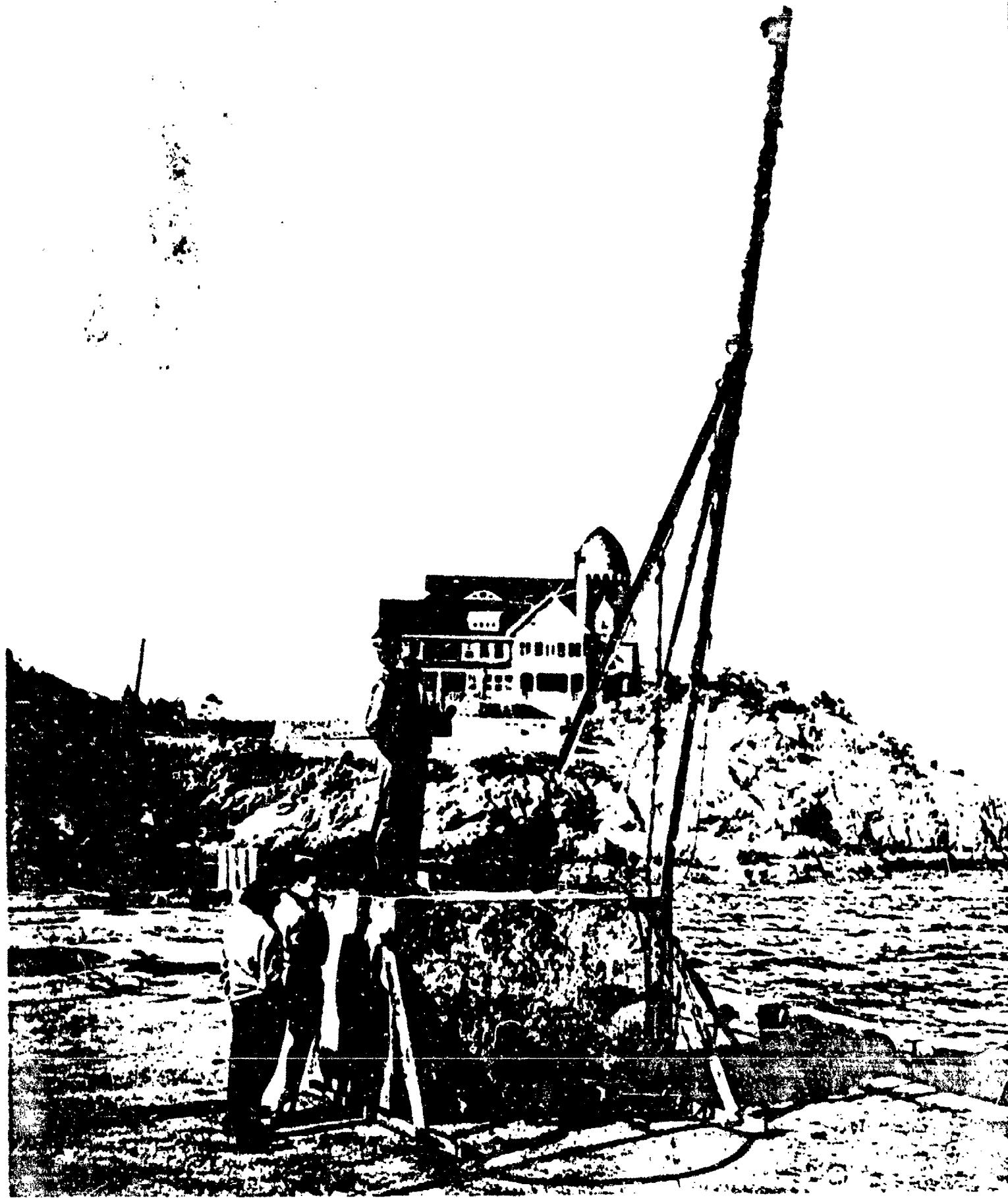
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Fig. 2 -- A pontoon used in 1952, recovered  
in summer 1953, 10 months later.

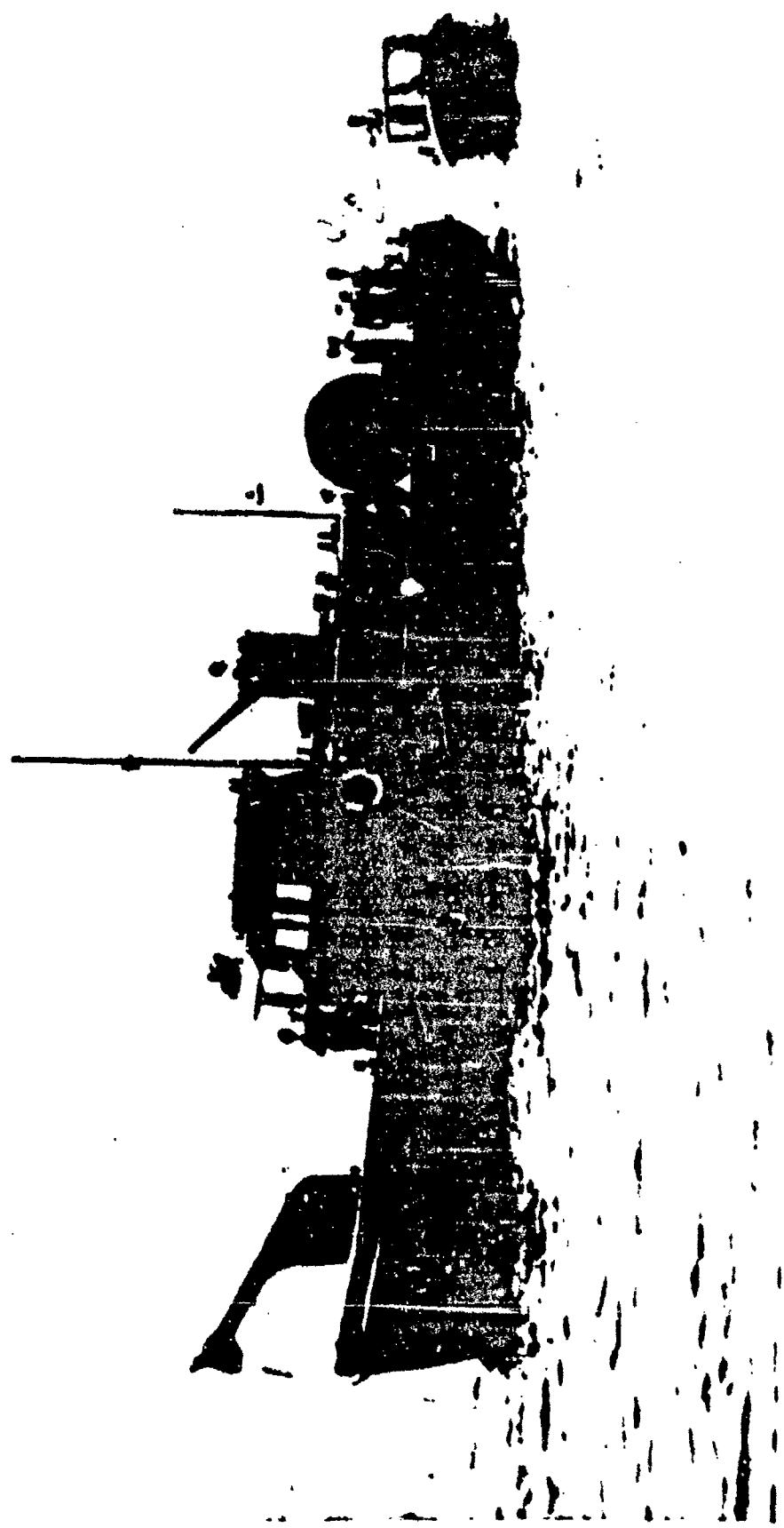
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Fig. 3 -- Cable laying vessels, 1953, west  
passage.

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Fig. 4 -- Cable on reel on L-Boat being put  
in water.

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Fig. 5 -- Putting cable ashore with oil-  
drum buoy, truck used to pull  
ashore.

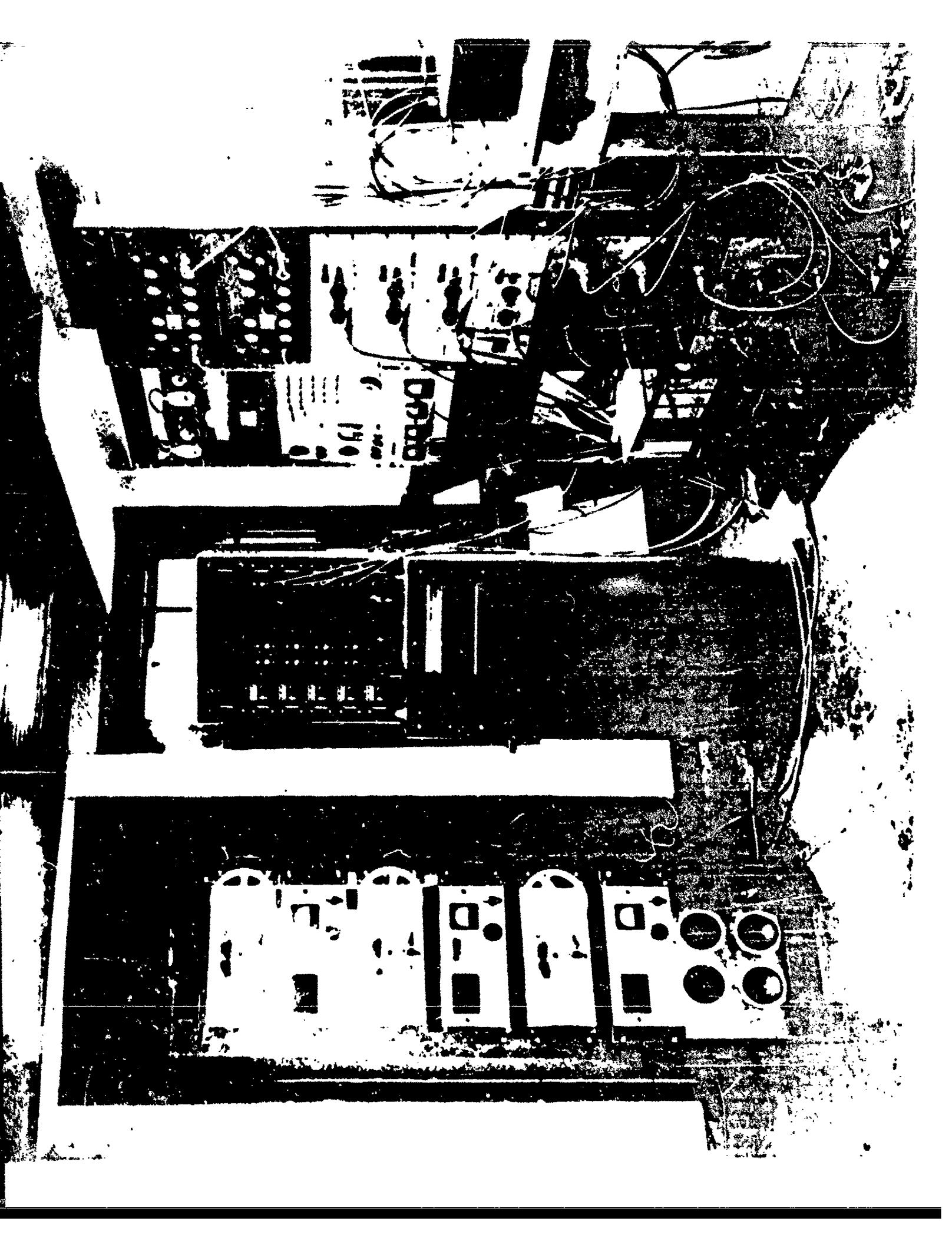
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Fig. 6 -- View in T-21 of shore equipment.

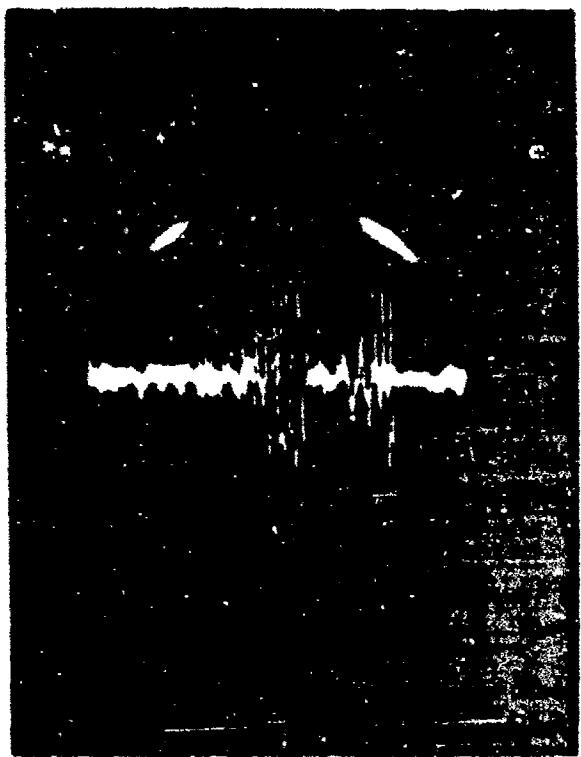
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**Fig. 7 -- Oscillogram of Mk 36 acoustic  
signal, 50-15,000 cps, 0.05  
sec/cm sweep speed.**

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Fig. 8 -- Sketches taken from individual frames of model mine water entry test films. The two examples are not to the same time scale.

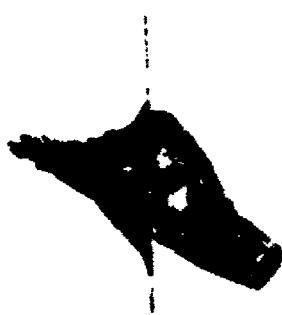
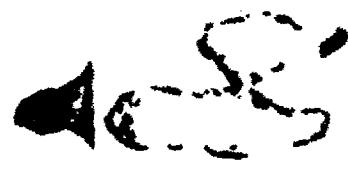
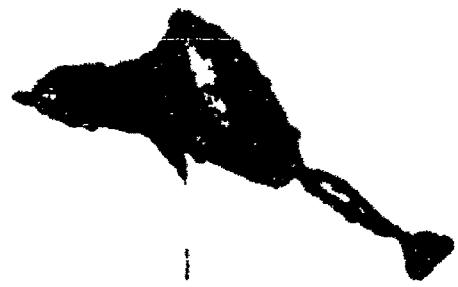
Upper line - Mk 36 model

- a. water contact
- b. water entry
- c. cavity formation
- d. full length of mine slaps side of cavity
- e. cavity continues to enlarge
- f. cavity continues to enlarge
- g. closure of cavity beginning close to mine
- h. closure complete around mine and progressing toward surface

Lower line - Mk 39 prototype model

- a. water contact
- b. water entry
- c. cavity formation
- d. full length of mine slaps side of cavity
- e. cavity continues to enlarge
- f. cavity closes at surface
- g. mine and cavity both move downward in water
- h. portion of cavity (on left) continues to move downward in water at speed much greater than rate of descent of mine itself

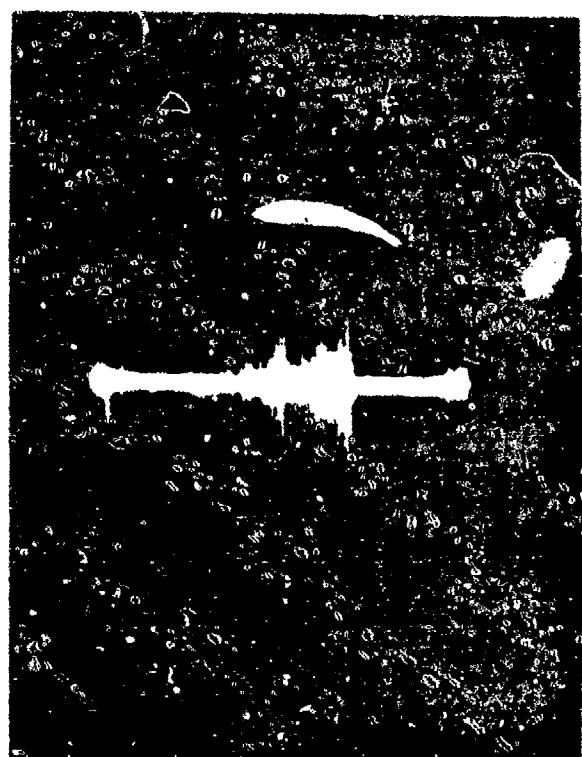
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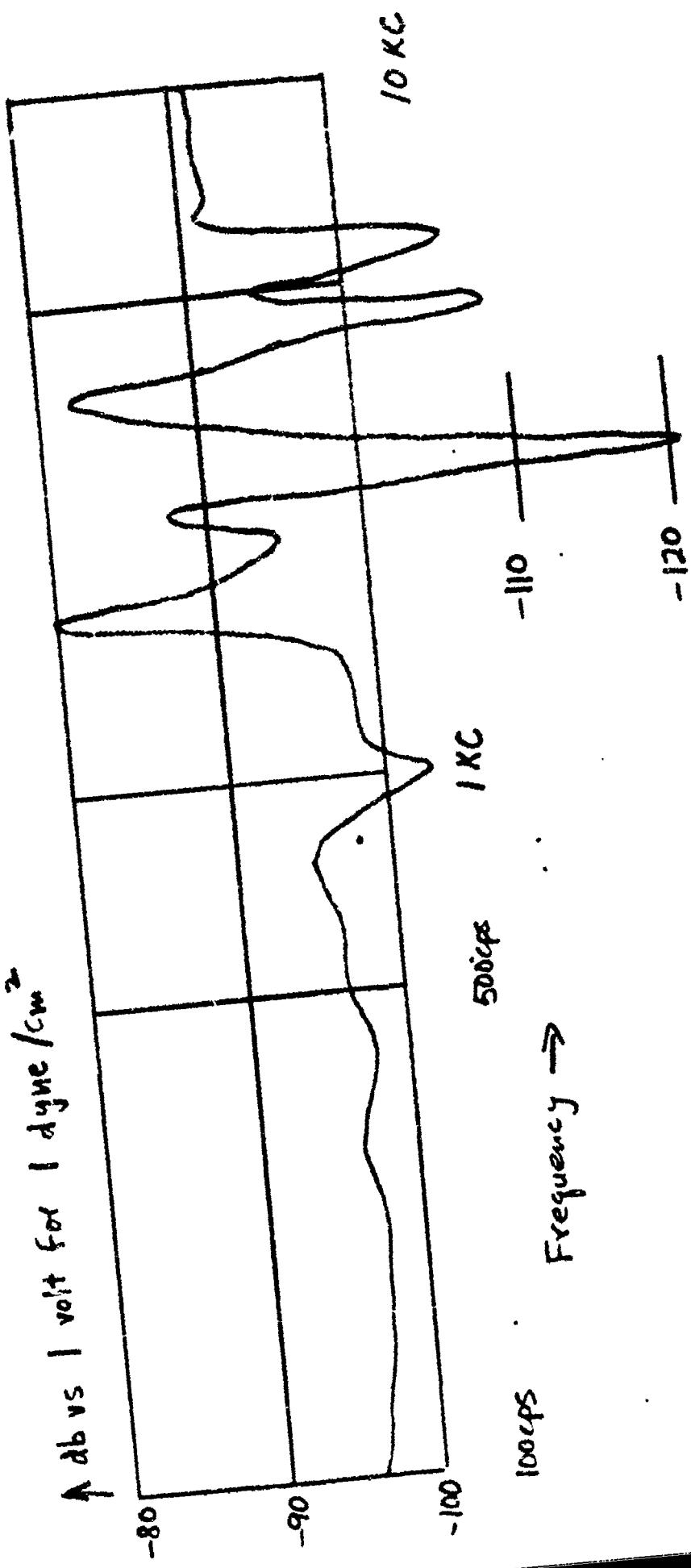


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Fig. 9 -- Oscillogram of Mk 39 acoustic  
signal, 50-15,000 cps, 0.2 sec/  
cm sweep speed.

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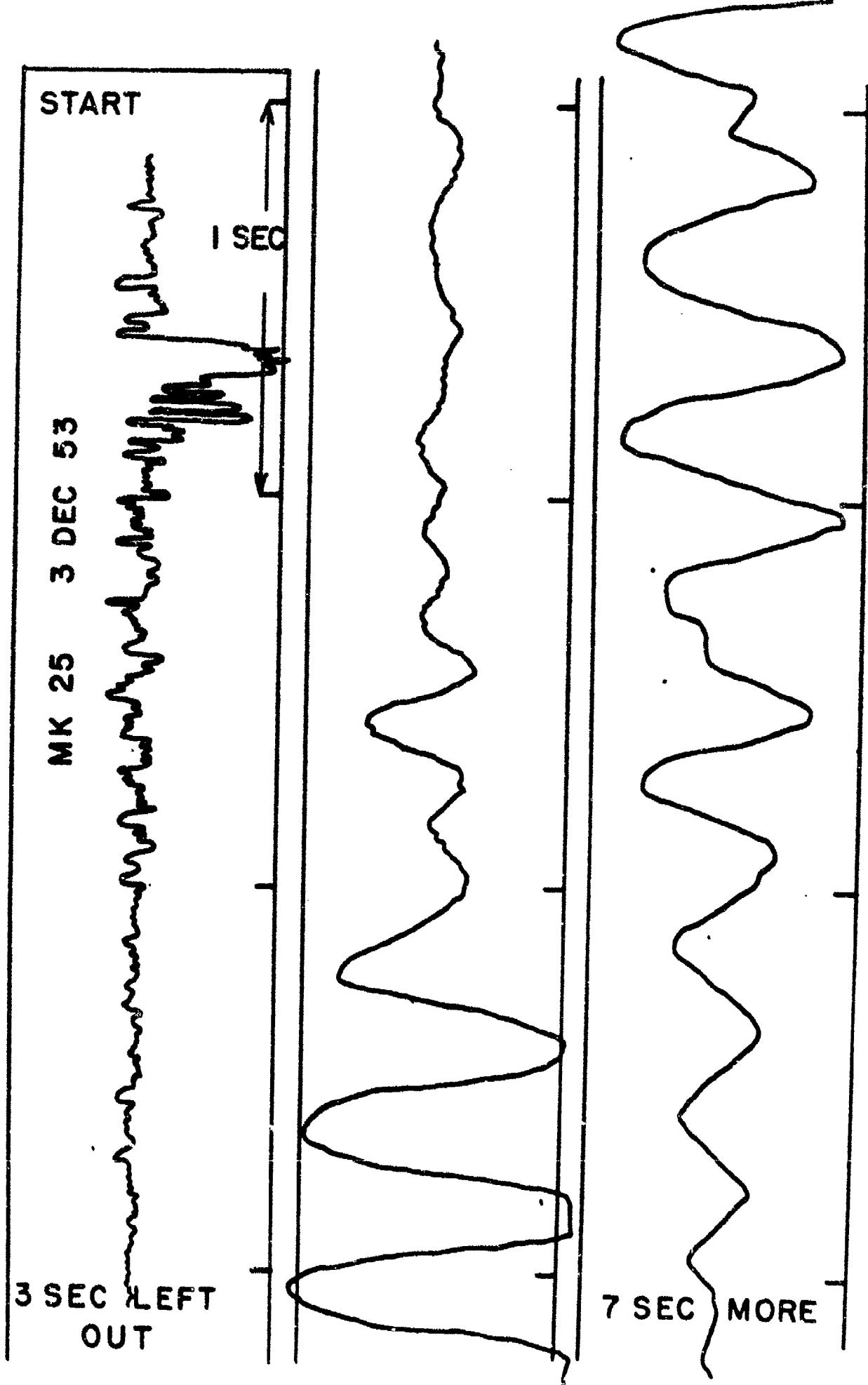
Fig. 10 -- Amplitude vs. frequency response  
of a typical Mk 6 Acoustic System  
hydrophone unit. Note extreme  
40 db excursion between 2 and 5 kc.

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Fig. 11 -- Signature of Mk 25 mine recorded at moderate distance. Note the pre-arrival disturbance which occupies approximately .3 second before the main arrival. Note also the very large oscillations which occur approximately 8 seconds after the start of the trace. These are associated with the mine colliding with the bottom. See also figure 12.

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Fig. 12 -- Oscillogram tracing of mine disturbance created simply by allowing mine to fall freely from just under the surface some 40 feet to the bottom. The disturbance at the start is the releasing of the mechanical holder on the mine. The oscillations (two similar tracings are shown in columns 2 and 3) occur some 10 seconds after the drop.

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